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DD/ST# 4684-68

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December 5, 1968

MEMORANDUM FOR

The Secretary of State
The Secretary of Defense
Chairman, Joint Chiefs of Staff
Chairman, U. S. Atomic Energy Commission
Director, Central Intelligence Agency
Director, Arms Control and Disarmament Agency
Director, Bureau of the Budget

I am transmitting for your information the report of the Ad Hoc Panel on the Safety of Underground Testing. At the request of the AEC, I appointed this panel, under the chairmanship of Dr. Kenneth Pitzer, to review the potential hazards associated with the underground testing of high-yield nuclear weapons.

The report raises a serious issue in its conclusion that there is a possibility that a large-yield underground test might trigger a severe earthquake which could produce serious damage well beyond the limits of the test site. I call your attention to the first three pages which contain the panel's principal conclusions.

I have given the President a copy of the report in connection with his consideration of the AEC's request for authorization to execute the

STAT [redacted] event.

Please note that the report is being handled on a privileged basis. A decision has not yet been reached as to whether to release it to the public.

I will be glad to discuss this report with you if you wish.

Donald Hornig

Donald F. Hornig
Special Assistant to the President
for Science and Technology

Attachment:
Ad Hoc Panel Report

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REPORT

of the

AD HOC PANEL ON THE SAFETY OF UNDERGROUND TESTING

November 27, 1968

Dr. Kenneth S. Pitzer, Chairman
Dr. Ray W. Clough
Dr. Lawrence R. Hafstad
Dr. James R. Killian
Dr. Gordon J. F. MacDonald
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Office of Science and Technology
Executive Office of the President
Washington, D. C.

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REPORT
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AD HOC PANEL ON THE SAFETY OF UNDERGROUND TESTING

The Panel received briefings on November 7, 1968, concerning the various potential hazards associated with underground nuclear explosions from the groups sponsored by the AEC to study these problems and from other experts. On November 8, 1968, the Panel met further with Dr. Glenn Seaborg and Dr. Gerald Tape of the AEC, after which discussions were held in executive session. The Panel's principal conclusions and recommendations are set forth in the following paragraphs. More complete assessments of the major areas of potential hazards are given in appended sections.

With regard to ground water contamination, direct seismic effects on structures, and radioactive venting, the Panel concludes that, while the possibility clearly exists that some damage will occur, there do not appear to be any major potential hazards with far-reaching consequences at the proposed level and locale of testing.

The Panel is seriously concerned with the problem of earthquakes resulting from large-yield nuclear tests. Although the possibility that underground nuclear tests might initiate one or more earthquakes has been suggested in the past, new and significant evidence demonstrates that small earthquakes do actually occur both immediately after a large-yield test explosion and in the following weeks. The largest of the observed associated aftershocks have been between one and two magnitudes less than the explosion itself. However, there does not now appear to be a basis for eliminating the possibility that a large test explosion might induce, either immediately or after a period of time, a severe earthquake of sufficiently large magnitude to cause serious damage well beyond the limits of the test site. This possibility is more serious for tests of greater than a megaton since the larger initial explosion would lead to greater alteration of the regional stress pattern. Further, it has recently been suggested that the great earthquakes (magnitude 8.5) are actually composed of a rapid succession of earthquakes of magnitude 6.5 to 7.0. Therefore, the fact that there have been two shots of approximately one megaton at Nevada Test Site without serious consequence does not give assurance that a future large shot might not result in a large earthquake.

The proposed tests at the central Nevada site involve a greater risk of earthquake than those at the regular Nevada Test Site since the more northerly portions of Nevada are more active seismically. Since the Amchitka area in Alaska is still more active seismically, the hazard of inducing an earthquake must be considered to be greater at that location than at either Nevada site.

The recent evidence indicates that the risks of damaging side effects from megaton tests are larger than were estimated when the proposed test series was planned. However remote and uncertain these risks may be, in the Panel's judgment they still raise new and serious questions about such tests and about the selection of sites for such tests. The need for each test, including the test proposed for December, 1968, should be given new consideration in the light of this new information. Consideration should also be given to the possibility of establishing a new high-yield test site in a non-seismic area.

The Panel expresses no judgment as to how important are the reasons for carrying out any one of the projected tests. However, the Panel does believe that the need for the tests as planned should be compelling if they are to be conducted in the face of the possible risks that have been identified.

In order to extend our judgment of nuclear event-related seismic hazards, the Panel recommends that future tests be accompanied by a more comprehensive seismic monitoring program, both pre- and post-shot, than has been carried out previously.

The Panel believes that the public should not be asked to accept risks resulting from purely internal governmental decisions if, without endangering national security, the information can be made public and the decisions can be reached after public discussion. In highly technical areas this discussion must take place primarily in professional circles. Moreover, there is great advantage in opening the consideration to professionally qualified persons who might make contributions to the understanding and solution of the problems. The Panel notes that most of the relevant information on all aspects of the problem is unclassified and that the essential parts of other reports could be released after editing to eliminate information about the particular nuclear explosive being tested. Consequently, the Panel recommends that as much information as possible concerning all of the potential hazards related to the continuing program of underground tests be released and that appropriate symposia be encouraged to facilitate discussion of these matters in the relevant professional communities in order that the general public may gain a better understanding of the problem.

* * *

I. Earthquakes and Slips Related to Underground Explosions

The potential seismic hazards from large-yield underground nuclear explosions include both the effects of ground motion resulting directly from the explosion and the effects of ground motion resulting from the triggering of earthquakes or slips as a result of the explosion. The hazard connected with the triggering of earthquakes is a more serious question because of the potentiality of releasing tectonic energy comparable to, or very much larger than, the energy of the explosion itself and at locations other than the carefully selected test site. We have only recently been confronted with this hazard because of the large yields of the devices being tested in the current program. We are now dealing with underground explosions with equivalent earthquake magnitudes in the range 6 - 7.

Although we can only speculate about the mechanism by which an explosion can trigger an earthquake, there is good evidence that great earthquakes consist of a superposition of smaller (magnitude 6 to 7) events triggered in succession. For example, data was presented last year which showed that the great Alaskan earthquake of 1964 was actually composed of a rapid succession of earthquakes of average magnitude 6.8. There is also evidence of a delayed reaction where an earthquake is followed by a second major earthquake in a contiguous region after a period of days or months. For example, the great Chilean earthquake (magnitude about 8.5) which produced a rupture of about 1,000 kilometers in length was preceded by a smaller earthquake (magnitude about 7.5) which deformed the northern part of this immense rupture zone the day before. A series of earthquakes in Nevada showed a similar phenomenon. The Fallon-Stillwater sequence occurred in July and August, 1954, each event with a magnitude 6.8. The Dixie-Fairview Peak earthquake sequence occurred in an adjacent area of the same seismic zone in December, 1954. The two shocks were four minutes apart and showed magnitudes of 7.1 and 6.8 respectively.

One hypothesis which may explain these phenomena proposes that a seismic belt is a region in which tectonic stresses produce regional deformation and a large amount of energy is stored in the form of elastic strain. An instability develops along a fault, slip occurs and a large amount of strain energy is released. Much recent work indicates that the stress drop of even the greatest earthquakes represents only a small fraction of the total stress in the rock around the fault. This stress is probably redistributed following an earthquake and concentrated at other points where the fault is locked. These lock points break rapidly, as in the case of an earthquake sequence. While this hypothesis is of course speculation, the main point to be considered in reviewing the hazards of large underground explosions is the observation that many destructive earthquake sequences seem to be related to individually recognized events in the magnitude 7 range.

There is no question that the larger nuclear explosions in Nevada have actually triggered small earthquakes and have produced slips along faults to distances up to about 40 kilometers. An earthquake in Southern California which occurred in the spring of 1968 with magnitude about 6. 5 produced displacements on faults at distances as great as 70 kilometers from the epicenter and well outside of the region of principal aftershock activity. Thus, explosions or earthquakes in the magnitude 6. 5 - 7 range can reasonably be expected to produce aftershocks, slips and stress readjustments to distances of the order of 100 kilometers from the epicenter. It is not clear whether these effects are due to static readjustment or whether they are induced by the dynamic stresses accompanying the large amplitude seismic waves. In any case, if there is high strain energy accumulation in a region within about 100 kilometers from a large explosion or earthquake, the possibility of triggering a major earthquake or starting a new seismic sequence has to be considered. Unfortunately, it is not yet possible to measure the absolute strain energy accumulation. Also, an earthquake is basically a process of instability and the experience with smaller explosions cannot be extrapolated to larger explosions as in the case of predicting ground motion.

Man's ability to intervene with the tectonic process was recently demonstrated in the case of the Denver earthquakes. These shocks occurred in a region which heretofore had been considered aseismic. Actually, this was a region of elastic strain accumulation and apparently locked faults. The pumping of fluids into a deep disposal well resulted in the unlocking of a major fault and the initiation of an earthquake sequence. Some well-known seismologists are now suggesting the possibility that a major earthquake may hit Denver as part of this man-induced earthquake sequence. The Denver experience may not be pertinent to underground testing in the sense that there is no analog to fluid injection. On the other hand, the Denver events may be pertinent if the Denver aftershock sequence is due to a shifting concentration of stress and the successive failure of lock points following the initial effects of fluid injection.

Nevada is a region in which destructive earthquakes are known to have occurred in historical times. The large number of faults which have been mapped and which show recent movements imply that Nevada has been seismically active for a much longer period. Tectonic stress is producing regional deformation in Nevada today and elastic strain energy is being stored in the rocks of the region. Amchitka is more seismic than Nevada by at least an order of magnitude. The hazards of triggering an earthquake in the Aleutians are different from Nevada. The triggered event may be larger in the Aleutians and it may excite a tsunami which could be destructive at great distances. However, not all of the larger earthquakes in the Aleutians produce tsunami. Nevertheless, if the triggered earthquake were a large one (magnitude greater than 8) and the rupture propagated to the east where the population density increases, there could be damage due to ground vibration as well as tidal waves.

The present level of understanding of seismic phenomena makes it difficult, if not impossible, to evaluate quantitatively the risks of conducting large underground tests in seismic regions. However, we know that seismic events in the magnitude 6 to 7 range can produce slips and aftershocks in the distance to range 10-100 kilometers. We also know that seismic events in the magnitude range 6 - 7 have been associated in the past as foreshocks to large earthquakes or as components of large earthquakes. In view of these observations, a risk must be associated with conducting large-yield nuclear tests in seismic regions. The risk seems to be small but not insignificant since the consequences of accidentally releasing a large amount of tectonic strain energy could be extremely serious.

Slips occurring on faults or bedding planes have led to the destructive failure of several dams in recent years. All dams within about 100-200 kilometers from large underground explosions (magnitude about 6.5 - 7) should be examined for the existence of faults and potential landslides which might be triggered by the explosion. Our concern here stems from the recently discovered slips (as distinct from aftershocks) associated with earthquakes and explosions in this magnitude range.

II. Direct Seismic Effects of Underground Testing on Building Structures

The ground motions generated directly by a major underground nuclear test are comparable to a moderate earthquake and present a potential damage hazard to buildings located in the vicinity of the test. Seismic waves from an underground nuclear explosion propagate outward from the source and induce ground vibrations which can result in damage of structures depending on the response of these structures to the amplitude and frequency of the vibrations. The motion of the ground at any point depends on the yield of the nuclear device, the medium in which the explosion occurred, the velocity-depth structure and attenuation characteristics along the paths followed by the seismic waves, and finally the characteristics of the soil and bed rock beneath the structures. By gathering a large number of observations of ground motion associated with underground tests in different media and with variable yields it is possible to evaluate these factors separately and to end up with a fairly good capability for predicting ground motion. Empirical scaling laws can be devised so that extrapolation to larger tests would lead to no surprises of a significant nature not predicted by the probability distribution of ground vibration deduced for the particular test site and its adjacent regions.

The AEC has of course recognized the potential direct seismic hazard from nuclear tests and has taken what it considers to be appropriate measures to insure the safety of structures which might be affected. An assessment of this problem can be conveniently divided into two phases: 1) the ground motions which may be developed at the site of each significant building, and 2) the effects produced in the buildings by these ground motions.

Prediction of Ground Motions. The ground motion generated by an underground test is a very complex function of time. It is neither feasible nor desirable to predict its exact time history at each building site. It is necessary only to predict those features of the ground motion which have a significant influence on the structural response. The AEC contractor that has been assigned the task of predicting ground motion has selected as its basic measures of the ground motion peak amplitude, the amplitude-frequency content, and the elastic response spectrum. For the purposes of building damage control, these should provide an adequate characterization of the ground motion; in fact, the elastic response spectrum itself is probably sufficient. However, it is important to note that these quantities do not completely define the ground motion, and are not suitable to predict the amount of damage which may be developed in a structure subjected to an excessive ground shock. The response in this case is inelastic, and is not proportional to the elastic spectral response.

The ground motion prediction techniques employed by the AEC contractor are essentially empirical extrapolation procedures based on measurements made in the critical structure areas (principally Las Vegas) during a large number of smaller events. These procedures seem to be quite suitable for the purpose of predicting ground motions which may have a significant effect on typical buildings in the vicinity of the main Nevada Test Site. The principal criticism which may be directed against the prediction effort is the fact that no basic hypothesis or analytical procedure has been developed which would make possible the calculation of motions to be expected from tests conducted at other sites and affecting other cities. Thus, it would appear that safety can be achieved in the proposed central Nevada and Alaskan test sites only by gradually increasing the yield and thus developing the necessary experience during the test program.

Specific questions that should be given greater consideration in the prediction effort concern the influence of local soil conditions and the effects of focusing by geologic structure on the motion characteristics developed at any given site. The influence of soil conditions could be studied quantitatively by establishing arrays of recording instruments located at fixed distances from the source and extending across widely differing soils (from solid rock to deep soft alluvium). On the basis of such measurements, it should be possible to devise analytical procedures which can account for the influence of ground conditions. The problem of focusing probably cannot be studied so easily, but efforts should be made to determine under what conditions and to what extent this factor may influence ground motion intensity.

The principal conclusion which may be drawn from the presentation on ground motion predictions is that the predictions are probably quite accurate for tests to be done in the Pahute Mesa area, and should provide for reliable estimates of damage to be expected in Las Vegas. Predictions made for tests to be carried out in central Nevada cannot be so reliable because of the limited experience with this area. Whether any damaging motions might be focused on Reno or some other city by these tests, and whether any special ground motion characteristics will result from the soil conditions present in these cities are questions which cannot be answered definitely at this time. However, results of the Faultless test indicate that there may be no special problems in this area.

<u>Prediction of Building Response</u>. The response of an elastic building to a specified ground motion is a standard problem of structural

dynamics, and can be carried out with great accuracy for any building for which the dynamic properties are known. The response spectrum techniques being employed by the AEC contractor are quite suitable for this purpose. The principal problem in the response prediction is the evaluation of the essential building properties. Vibration-mode shapes and frequencies and viscous-damping ratios are probably the most significant structural characteristics, and these can be obtained experimentally either from preliminary low-yield test excitations, or from other dynamic inputs.

The principal difficulty in the response prediction problem is the estimation of the strength capacity of the buildings subjected to ground motions. Reasonable estimates can generally be made of the strength of the basic structure, but the non-structural components such as partitions, plastered walls, window systems, etc., have rather indeterminate force or deformation capacities. The extensive monitoring of buildings for damage, as is being done by the AEC contractor, is probably the most effective means of establishing these strength properties in practice.

In general, it may be concluded that the response prediction work of the AEC contractor is comprehensive and effective, and provides satisfactory estimates of the damage to be expected in Las Vegas. Presumably, similar work will be done in the cities which may be affected by ground motion generated from the central Nevada test site. The only major criticism which may be directed toward this phase of the work is that the technical results which are developed from these underground tests are not being released to the scientific community. These tests are equivalent to earthquakes in many respects, and the response analyses and measurements are of great significance to earthquake engineers. These measurements will be even more valuable if and when incipient damage is developed in any of the observed buildings, and it is important that all results be released to the profession as soon as is practicable.

III. Effect of Underground Testing on Earth and Concrete Dams and Embankments

Soil and concrete structures may be subjected to damage by the ground shaking accompanying a nuclear event, or by displacement, induced by the event, along a geological fault running through the structure. Several types of soil behavior can occur: the soil can be a vibration transmitter to a structure; the soil can fail, resulting in the sliding of soil masses; and the soil can slump or subside as a result of compaction or densification effects, which are intensified in saturated soils due to liquefaction. Soil slides and flows can also occur under water. Damage can occur in concrete dams such as cracking of the structure, motion of the dam with respect to its abutments or foundations, and disturbance of the generating equipment requiring realignment. Rock falls can occur as a result of ground shaking. If soil slides or rock falls occur in reservoir side slopes, the resulting water waves can cause damage to the dam and appurtenant structures, as well as along the reservoir margin.

Observed Effects at NTS. A substantial number of ground motion records have been obtained at Nevada Test Site over a wide area from a variety of tests. No highway or other embankment slope failures have been recorded. In the vicinity of some shot points ground cracking has been observed which was attributed to geological faulting propagated through the alluvium. It is not clear whether or not some proportion of this cracking is in fact attributable to local soil compaction or slumping effects. Soil slope failures and rockslides in areas adjacent to shot points have occurred. Since fault displacements at unexpected distances from ground zero have been detected essentially accidentally after events, it is not known to what distance rock falls or soil slides might have occurred.

At Hoover Dam, records of small (0.005g) accelerations have been made on the dam. These have not been accompanied by observed damage. There have been no records of rockfalls or soil slides into Lake Mead.

Earthquakes near Hoover Dam apparently not associated with nuclear tests have interrupted power transmission from the Hoover Dam power plant as a result of relay vibrations. Some of these earthquakes have been associated with the filling up of Lake Mead and are thus another example of human intervention in tectonic processes. The flow of the Colorado River into Lake Mead since construction of Hoover Dam has been accompanied by a gradual deposition of silt in the reservoir floor. Periodic changes in the elevation of the silt reservoir bed have been observed due to underwater slides, flows, or turbidity currents in the silt.

Possible Future Effects at NTS and Amchitka. Considering the present levels of ground motion recorded at or near Las Vegas for Project Boxcar, tests at Pahute Mesa and the central Nevada test site, with yields up to two and four times respectively those of the largest events conducted to date, do not appear likely to cause soil disturbance of the types cited. The soil vibrational response in Las Vegas due to the Boxcar event has apparently reached levels which, combined with the response characteristics of some buildings, are on the point of causing minor amounts of architectural damage.

In Amchitka, Alaska, underwater soil slides may be generated by a nuclear test although the offshore soil conditions are uncertain. Submarine soil slides may generate tsunami waves. In the past, several large tsunamis have been associated with soil slides.

In summary:

1) There is no evidence at present to indicate that future tests at Pahute Mesa up to twice the yield or at central Nevada Test Site up to four times the yield of the largest events conducted to date will be hazardous from the point of view of soil behavior.

2) There is a need to obtain more soils information in the immediate vicinity of ground zero and to examine more carefully the detailed nature of crack and displacement patterns observed on the surface after tests, to clarify their relation either to faulting in bedrock or to local soil slumping or other movements not directly related to bedrock faulting. The behavior of soil and rock slopes around Lake Mead could be more carefully examined pre- and post-shot. The position of the silt surface at the bottom of Lake Mead could also be studied before and after future events. Some of these additional studies could be carried out in such a way that they would supply information of significant assistance to the solution of current earthquake engineering problems.

3) Since some structural damage during earthquakes appears to result to structures as a consequence of their prestressing by poor soil or foundation conditions, such damage may not be predictable by the techniques employed by the safety organization at NTS and therefore it appears desirable that more emphasis be given to the examination of soil conditions and their relation to structural conditions at Las Vegas or other inhabited areas, as well as over the test site generally.

4) There is at least a possibility that in Amchitka soil behavior might result in the development of underwater slides that could conceivably result in the generation of tsunamis. More attention should be given to this problem.

5) Structures for which a damage potential exists (in particular, dams, reservoirs, water tanks) within a radius of 200 km should be monitored before and after each of the larger tests.

IV. Ground Water Contamination Hazards

Radionuclides released from large underground nuclear explosions are distributed initially by direct action in the immediate vicinity of the explosion. If the shot point is near or below the water table, the nuclides may be transported by ground water in possibly hazardous concentrations.

Because ground water generally moves at velocities measured in terms of feet per year, only long-lived radionuclides are important in water transport. The biologically significant radionuclides in this category include H^3 (tritium), Ca^{45}, Co^{60}, Sr^{90}, Cs^{137}, Ru^{106}, and Ce^{144}. Laboratory and field experiences have demonstrated that all of these nuclides except tritium are strongly adsorbed by exchange with cations on the surfaces of clay materials; consequently, their movement is only an insignificant fraction of that of the ground water with the result that their concentrations fall below the maximum permissible concentration (MPC) within a short distance from ground zero. However, the disposition of radionuclides in limestone or dolomite is more complex and in these rocks the absorption may be substantially less than in volcanic rock. For tritium, a negligible exchange between tritiated water and the rock matrix must be assumed. Thus, in terms of curies of activity tritium represents the most abundant nuclide in ground water from a large fusion-fission explosion and becomes the primary contaminant in ground water.

Assuming tritium moves as an ideal tracer with ground water, it will travel in the direction of the local water table gradient and at a velocity governed by the magnitude of the gradient and the permeability of the aquifer. Although average values of gradients and permeabilities in a particular medium can be determined from well data, movements of tritium one to two orders of magnitude greater than the average ground water velocity can be expected as a result of 1) local heterogeneities in aquifers, particularly openings such as solution tubes, fractures, and faults, and 2) dispersion resulting from hydrodynamic mixing as water travels through an actual porous media. Transport can be most rapid through formations such as limestones, basalts, and coarse-grained alluvial deposits which contain large openings.

Experience gained from waste disposal operations at Hanford shows that maximum ground water velocities can be several-fold greater than the average velocity and that without extensive subsurface information the location and direction of these high-velocity tongues are impossible to predict. Similarly post-shot field tests at Project Gnome revealed velocities some 25 times greater than expected values.

At the Nevada Test Site subsurface hydrological investigations have defined the regional ground water flow pattern and average rates of flow. Water tables in the area are deep, exceeding 1600 feet, because of drainage to the south through underlying carbonate formations. Although permeabilities are large, water table gradients are low and consequently velocities are small. Exploratory well data have thus far revealed no evidence of continuous underground conduits which could permit high ground water velocities; nevertheless, the possibility of such heterogenities must be recognized and an active program of testing maintained. There is no reason, based upon evidences collected to date, to believe that tritiated ground water will reach the discharge areas, some 50 miles south of NTS, at concentrations above the maximum permissible concentration (MPC).

At the Central Nevada site ground water occurs at depths of less than 600 feet and drains into Railroad Valley. This is a closed basin with ground water approaching land surface in the lowest portion of the valley where it is lost by evaporation to the atmosphere. As long as use of ground water in the valley is carefully restricted, no problem of tritium contamination is foreseen.

At Amchitka, the water table is everywhere near ground surface. Any shot point will be within roughly two miles of the shoreline and the water table gradient will be greatest in a seaward direction. With relatively little information available on aquifer conditions, the greatest movement of ground water would be anticipated along one of the numerous transverse faults on the island. On this basis tritiated water at levels above the maximum permissible concentration (MPC) would be discharged into the Pacific Ocean; however, the resulting immense dilution would rapidly dissipate excessive tritium concentrations.

On the basis of the above summary, it appears probable that future underground tests of large magnitude at the three test sites will not create hazardous ground water contamination. It should be emphasized, nevertheless, that because of the uncertainties of localized geology, continued surveillance monitoring of ground water is essential to insure that unexpected high concentrations of any radionuclides do not go undetected.

V. Radioactive Venting

Underground nuclear tests are normally buried at depths designed to prevent the venting of any radioactive material. The problem of assessing the hazards from radioactive venting therefore consists of first establishing the probability that some radioactivity might be released despite the efforts to contain it and then determining the biological significance of that amount of radioactivity. The Panel did not consider the special problem of radioactive venting from underground nuclear excavation tests which are not designed to be completely contained and are expected to release a small fraction of the produced radioactivity to the atmosphere.

As a result of the extensive U. S. underground nuclear test program, there is a considerable amount of data available on the containment of nuclear explosions over a very broad range of yields (from a fraction of a kiloton to the order of one megaton). On the basis of this information, scaling laws have been developed that permit calculation with a high degree of confidence of the depth of burial required to contain an underground test of any anticipated yield. When these scaling laws are applied to tests with yields of more than a few tens of kilotons, experience indicates that there is very little chance that there will be any radioactive venting.

Out of over 150 underground nuclear tests, only 10 have resulted in a significant amount of radioactive venting. It should be emphasized that in each case the radioactivity involved constituted only an extremely small portion of the total radioactivity produced in the nuclear test. All of the tests that have vented involved relatively small-yield explosions. The largest of these tests had a yield of a few tens of kilotons, and the majority of the tests had yields of a few kilotons. Subsequent investigation of these unanticipated ventings of small amounts of radioactive debris indicate a variety of probable causes such as the existence of unknown faults in the vicinity of the test location and leakage through and around test cables and pipes. The largest test (a few tens of kilotons) that has produced a significant amount of radioactive venting was a special case in that it was conducted in dolomite, a medium not ordinarily for testing. The non-condensable carbon dioxide released in the explosion apparently diffused to the surface carrying fission products with it.

When one considers higher-yield tests, there is no evidence of any radioactive venting at all. Specifically, in none of the approximately 20 tests with yields of from roughly 100 kilotons to about a megaton has there been any radioactive venting.

The general explanation for the fact that the smaller the explosion, the greater the probability that there may be some venting is probably that accidental venting results primarily from the existence of unknown faults in the surrounding media. In the case of small shots near the surface, a single fault may extend far enough to permit venting. The deeper the shot is buried, the less likely it is that a single fault will extend far enough to provide a sufficient channel for venting to develop.

Whenever an accidental venting occurs, the AEC has standard procedures to determine the quantity of material vented and to monitor the cloud if it should extend beyond the test site. If levels are high enough, there are adequate stand-by procedures to warn local residents and to check that the milk from local dairy cows does not contain unacceptable levels of radioactive iodine.

The Panel made no effort to reassess the health hazard from the very small exposures that might result from such radioactive venting accidents as have occurred in the past. However, although some health hazard presumably results from any exposure, the amount of radioactivity resulting from these accidental radioactive ventings has been so small and so localized that the safety hazard appears to be minimal.

The case of Amchitka is somewhat more complicated than Nevada since there has been only one underground test at that location. There is also a possible additional problem in that there appears to be extensive local faulting, which is not easily identified from the surface. At the same time, any radioactive venting that does occur at Amchitka presents less of a safety hazard in view of its remote location. Therefore, since it is planned to build up to the highest-yield test planned at Amchitka with a series of tests of increasing yields, there does not appear to be reason to anticipate special safety hazards from venting if conservative scaling factors are followed.

In summary, the Panel concludes that there is relatively little safety hazard at the NTS from radioactive venting from large-yield shots. Based on rather extensive experience, it appears to be very unlikely that there will be any radioactive venting from these shots. Moreover, if venting should occur, it would almost certainly involve small amounts of radioactivity which would not constitute a significant health hazard. The Panel is somewhat less certain about the prospects for complete containment at Amchitka in view of our very limited experience at that location and the existence of local faults in the vicinity of the test site. Nevertheless, significant venting from large shots at Amchitka appears very unlikely; and, if it should occur, the remote location would minimize the resulting health hazard.